

X. COST, SCHEDULE, MANPOWER, AND FUNDING

X.1. Detector Scope

The detector configuration necessary in order to accomplish all the physics goals encompassed in this report includes the following:

- The full EMC barrel consisting of 120 calorimeter modules (with internal shower maximum, and pre-shower detectors)
- One endcap calorimeter (with internal shower maximum, and pre-shower detectors)

In nucleus-nucleus collisions, the barrel calorimeter provides the means to measure the neutral transverse electromagnetic energy. In addition to affording a more detailed understanding of the transfer of energy from the projectile frame to mid-rapidity, the improved resolution in determining the total transverse energy deposition will allow the creation of highly selective triggers in order to search for rare events predicted to result if a color deconfined plasma of quarks and gluons is produced. Since both the coverage of the barrel calorimeter and measurement of the neutral energy are necessary for the detection of jets, the barrel EMC is also necessary to utilize the interaction of hard-scattered partons with the surrounding medium as a penetrating probe of the early stages of the collision. Additionally, the measurement of jets within the coverage of the barrel is necessary for the study of gluon shadowing in pp and pA interactions, which is essential if the particle production in nucleus-nucleus collisions at RHIC is to be understood.

The acceptance of the endcap calorimeter is necessary to study gluon shadowing in pp and pA interactions and to detect gluon and quark jets in polarized pp interactions in order to determine the contribution to the proton spin from the angular momentum carried by gluons. Since both of these studies are most easily carried out by studying the $qg \rightarrow \gamma q$ Compton subprocess, efficient detection of direct photons above $p_t \sim 10$ GeV/c is essential. The shower maximum detector provides the fine spatial resolution necessary to distinguish direct photons from photons emanating from π^0 and η^0 decay.

The modular nature of the calorimeter design makes it possible to stage the construction of this detector in a number of ways. Depending upon which staging plan is adopted, the physics capabilities of the EMC also vary. The present report addresses one specific option. In this option, all 120 calorimeter modules will be constructed over a period of four years, starting with fabrication in early 1999. Each module will contain a gas wire-strip shower maximum detector together with its on chamber readout electronics, and the optical components required for the pre-shower detector. The phototubes and readout electronics for the pre-shower detector will be deferred until a later date. However, it is essential that the optical fibers be installed during module construction due to the impracticalities involved in retrofitting them. These fibers only constitute a few percent of those required for the barrel calorimeter and the additional costs involved are small. The completed modules would be installed during summer shutdowns at RHIC, together with their complete readout and triggering electronics allowing the full $\Delta\phi \times \Delta\eta$ segmentation of 0.05×0.05 to be fully realized for each module after installation. The barrel calorimeter is expected to be complete in 2003, at which time it will have 4800 readout channels. The support system for the calorimeter has been specifically designed for this staged detector construction, and allows for the installation of modules without

removing other detector components from STAR. This system has been built, and is in place in the STAR magnet for the full barrel EMC. Construction of the endcap calorimeter would be deferred at this time. Provisional estimates of the cost of this option is \$12.6M in FY98 dollars including \$2.2M in contingency. Several areas have been identified in which contributions from participating institutions could result in significant savings. These include machining of mechanical components, labor for module assembly, and fabrication of the shower maximum detector. The estimated total cost of components and labor which will contributed is \$11.2M in FY98 dollars, and these savings have been included in generating the \$12.6M cost estimate for the calorimeter.

The physics provided by this implementation of the calorimeter is significant. Specifically, with the full EMC barrel, the resolution on the reconstructed global transverse energy for AuAu interactions, for example, will improve to $\sim 2\%$. The resolution available at the trigger level for the global neutral transverse energy would be $\sim 2.5\%$. With this resolution, STAR will be able to search at the trigger level for events exhibiting unusual isospin abundances or unusual correlations between energy density and entropy density. Additionally, the improved resolution provided by the EMC will afford a more detailed understanding of the transfer of energy from projectile rapidity to mid-rapidity. As the EMC barrel is large compared to a jet radius ($\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \leq 0.7$) it will also be possible to measure inclusive jets and high p_t π^0 's from parton scatters within $|\eta| \leq 0.3$, or larger with out of cone corrections. This will allow STAR to study the energy loss of hard-scattered partons using inclusive jets as well as γ -jet and jet-jet coincidences.

With the subsequent addition of one of the endcap calorimeters, instrumented with a shower maximum detector, the measurement of gluon shadowing in pA collisions would be possible. This would allow STAR to determine the initial conditions in AA interactions and make full use of perturbative QCD in predicting the pre-equilibrium phase of the collision. Funding for an endcap calorimeter is currently being sought from other sources.

As discussed in section X.3, the back loading of the calorimeter funding profile means that only $\sim 20\%$ of the funding is available in time for Day 1 operations at RHIC. Completing the required electronic and electrical engineering, and the necessity to fund and install all of the barrel calorimeter support system by March 1998, so as to avoid the subsequent removal of the TPC, further reduces available funds for the Day 1 detector. In order to maximize the detector coverage, several aspects of the EMC electronics are also designed to be staged. The interface to DAQ will eventually involve sending all of the EMC data to 24 TPC crates for use in the Level 3 trigger. This will be simplified to one interface card for early running. The EMC Level 0 trigger can provide basic quantities such as E_t , high tower energy for photons, a crude jet trigger, and luminosity scaler data at Day 1 with limited electronics. It will be upgraded for more sophisticated electron, photon, and jet triggers as funding allows.

As discussed in section X.3, we expect to have about 10% of the detector modules in place for Day 1 physics. The design, prototyping, and some early production of electronics will be done before Day 1 to ensure our ability to utilize the EMC in the RHIC physics program. The Day 1 detector implementation will have physics

capabilities for several measurements in AuAu and pp within a limited solid angle. The detector's trigger capability, while limited with respect to a full calorimeter, will be a significant addition to STAR as it forms the only trigger based upon energy and not just multiplicity.

X.2 Detector Summary Cost Estimates

The projected costs of the Barrel EMC and SMD have been re-evaluated since the original estimates, by the Argonne National Laboratory and the Lawrence Berkeley Laboratory, presented in the CDR. This re-evaluation has been done by the participating institutions that will be responsible for delivering each of the appropriate subsystems to the experiment. These cost estimates have taken into account the considerable changes in the mechanical design of the detector required to provide increased mechanical segmentation, along with the considerably more advanced schemes for the electronics, trigger, and data acquisition. The costs presented here include considerable contributions from the participating institutions, both in terms of labor and facilities, as well as significant savings over National Laboratory Labor rates. Such savings amount to \$11.2M for detector configuration discussed here.

The summary cost estimates in FY98 dollars for the detector considered here are presented in Table X.2-1. They include EDIA, labor, materials, and contingency, but do not include the EMC prototype funding received in FY96. The average contingency of the EMC barrel and SMD is ~21%. The cost projection below includes funding for the complete module installation tooling, but installation labor for just the Day 1 modules. It is presently thought that by the time the FY00 calorimeter modules are ready for installation, STAR will be eligible for support from RHIC operations. In this instance, most of the installation of the barrel EMC modules would be performed by riggers and technicians supported by RHIC with supervision provided by STAR personnel.

		%	K\$				
WBS #	WBS OR ACTIVITY DESCRIPTION	CONT	MATL	LABOR	WBSBASE	CONT	TOTAL
4.5	ELECTROMAGNETIC CALORIMETER	21	6249.1	4135.1	10384.2	2220.0	12604.2
4.5.1	BARREL TILE CALORIMETER	21	5650.4	3234.7	8885.1	1878.3	10763.4
4.5.1.1	Converter Plates and Module Structure	18	672.7	122.8	795.5	140.6	936.1
4.5.1.2	Tile-Fiber System	20	1857.1	632.1	2489.2	500.7	2989.9
4.5.1.3	PMT System	23	1153.9	101.9	1255.8	286.5	1542.3
4.5.1.4	Calibration Systems	25	79.6	44.4	124.0	30.6	154.6
4.5.1.5	Module Final Assembly, Tests, and Shipment	24	416.2	540.7	956.9	228.3	1185.2
4.5.1.6	EMC Prototypes	0	30.0	1.4	31.4	0.0	31.4
4.5.1.7	Transportation and Handling Systems						
4.5.1.8	EMC Installation and Test	22	226.1	361.3	587.4	131.6	719.0
4.5.1.9	EMC FEE	29	519.5	407.6	927.1	273.5	1200.6
4.5.1.10	EMC Contribution to DAQ System	24	34.5	191.9	226.4	54.0	280.4
4.5.1.11	EMC Contribution to Online System	25	7.0	87.6	94.6	24.0	118.6
4.5.1.12	EMC Contribution to Trigger	16	177.5	0.4	177.9	28.5	206.4
4.5.1.13	EMC Controls	18	61.2	19.4	80.7	14.8	95.5
4.5.1.14	EMC Level 1 Trigger						
4.5.1.15	EMC Conventional Systems	13	140.0	17.5	157.4	20.5	177.9
4.5.1.16	Project Integration and Management	22	0.0	649.8	649.8	144.7	794.5
4.5.1.17	Module Supports	0	275.1	55.9	331.0	0.0	331.0
4.5.2	BARREL SHOWER MAX	23	598.7	900.4	1499.1	341.7	1840.8
4.5.2.1	Chambers	20	241.5	545.0	786.5	157.7	944.2
4.5.2.2	Shower Max Prototypes (full scale)	22	21.3	29.6	51.0	11.1	62.0
4.5.2.3	Transportation and Handling Systems						
4.5.2.4	Shower Max Electronics	29	268.3	317.8	586.1	167.6	753.7
4.5.2.5	Shower Max Conventional Systems	7	67.5	8.0	75.6	5.4	80.9

Table X.2-1. The estimated cost of the EMC detector including the EMC modules, their support structure and associated electronics, installation and testing, project management, and systems integration including EDIA in FY'98 dollars. The total cost of the calorimeter and SMD is given in WBS # 4.5. The cost of the EMC and the SMD are given separately under WBS #'s 4.5.1 and 4.5.2 respectively. The costs associated with Transportation and Handling Systems (WBS items 4.5.1.7 and 4.5.2.3) have been relocated under the WBS number of the system to which they pertain, and hence these line items have zero cost. Level 1 trigger is deferred.

X.3 Funding Profile and Schedule Estimates

All of the engineering required to interface the barrel calorimeter to the STAR detector has already been carried out, and the module supports and rail systems are fully installed into the STAR magnet. In addition, the engineering directed at the design of the calorimeter modules, and the choice of technology has been accomplished, meaning that the EMC modules are now ready to enter a construction phase. Initial funding received would be devoted to completing the electronic engineering of the EMC and SMC readout, and the setup of the module construction facilities, initially at Wayne State, with a second construction facility being added later at Argonne National Laboratory when

funds permit. Upon completion of this setup phase, full-scale module production would commence in early calendar 1999.

The funding profile assumed in the following schedule estimate for the construction of the detector is shown in Table X.3-1 below. This profile, and the previous cost estimates, do not include the EMC prototype funding received in FY96.

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03
Funding per FY \$k	\$0k	\$600k	\$1,000k	\$2,000k	\$2,300k	\$2,300k	\$2,300k	\$2,104k
Cumulative Funding \$k	\$0k	\$600k	\$1,600k	\$3,600k	\$5,900k	\$8,200k	\$10,500k	\$12,604k

Table X.3-1: Assumed funding profile (FY98 dollars) for the construction of the STAR Electromagnetic Calorimeter including 4800 towers, the barrel SMD, and the pre-shower optical components.

The majority of the funds received in FY97 were required for completion of the EMC support system. Most of the funds received in FY98 and FY99 would be required for the setup of the EMC module production facilities and the remaining electronic and electrical engineering to complete the design of the calorimeter readout electronics and trigger. Module construction would begin in early 1999. Under the assumption that none of the contingency is required to be spent, and that all funds received can be applied to the base cost of the detector, the module production profile would be as shown in Table X.3-2. Table X.3-3 shows the module production profile under the assumptions that the full contingency is needed on each WBS activity as that activity is completed. Table X.3-2 can be regarded as the most optimistic approach, whilst table X.3-3 can be regarded as a pessimistic approach. It is likely that these two table bracket the expected module production rates and thus the expected number of modules available for Day 1 operations will be between 8 and 18 modules.

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	Total
# Modules per FY	0	0	0	18	33	36	34	0	120
Cumulative # of Modules	0	0	0	18	50	86	120	120	

Table X.3-2. Estimated rate of module production for the STAR Electromagnetic Calorimeter given the funding profile shown in Table X.3-1, and the assumption that zero contingency is required. This can be regarded as the most optimistic approach. The rate of module production is funding, not facility, limited and consequently the spending of contingency will lead to slippage from these production numbers.

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	Total
# Modules per FY	0	0	0	8	26	29	29	27	120
Cumulative # of Modules	0	0	0	8	34	64	93	120	

Table X.3-3. Estimated rate of module production for the STAR Electromagnetic Calorimeter given the funding profile shown in Table X.3-1, and the assumption that the full contingency is needed on each WBS activity as that activity is completed. This can be regarded as a pessimistic approach.

These production profiles are funding limited. Schedule estimates of the production of similar calorimeter modules for ZEUS suggest that such modules could be completed at the rate of ~30 per year, per facility, making the maximum module production rate ~60 per year for the two construction sites.

The resource-loaded schedule is shown in Figures X.3-1 and X.3-2. The schedule again makes the assumption that none of the contingency is required. Figure X.3-1 shows the schedule leading up to Day 1 physics with a calorimeter patch of between 8 and 18 modules. It highlights the principle activities scheduled between now and Day 1. These are:

- The construction of a complete full sized mechanical prototype module and the subsequent tests of the installation protocols with a full sized mockup of a sector of the STAR magnet.
- Installation and removal of the full sized mechanical prototype into the STAR magnet to test the module installation tooling and procedures prior to the TPC being installed.
- The construction of a second, fully functional, prototype and the activities leading to its testing at BNL in October '98 to establish the relationship between the module's response to real particles and the various calibration methods that will be employed.
- The completion of the electronic and electrical engineering required to finalize the design of the readout electronics and trigger.
- The completion of the module construction facilities.
- Construction and installation of the first modules and their associated electronics.

Figure X.3-2 shows the module construction schedule after Day 1 and until the completion of the barrel calorimeter. What is clear from the schedule is that module construction continues over a relatively long period, with major procurements being staged to avoid periods of discontinuity. With the modular design of the EMC, modules

constructed in one year will be installed when the STAR detector is rolled out into the Assembly Building during the RHIC shutdown of the following year. Under the assumed profile and schedule estimate, the last modules are installed during the RHIC summer shutdown in 2002. Spending on contingency will cause some slippage, resulting in the last modules being installed during the summer shutdown in 2003 instead.

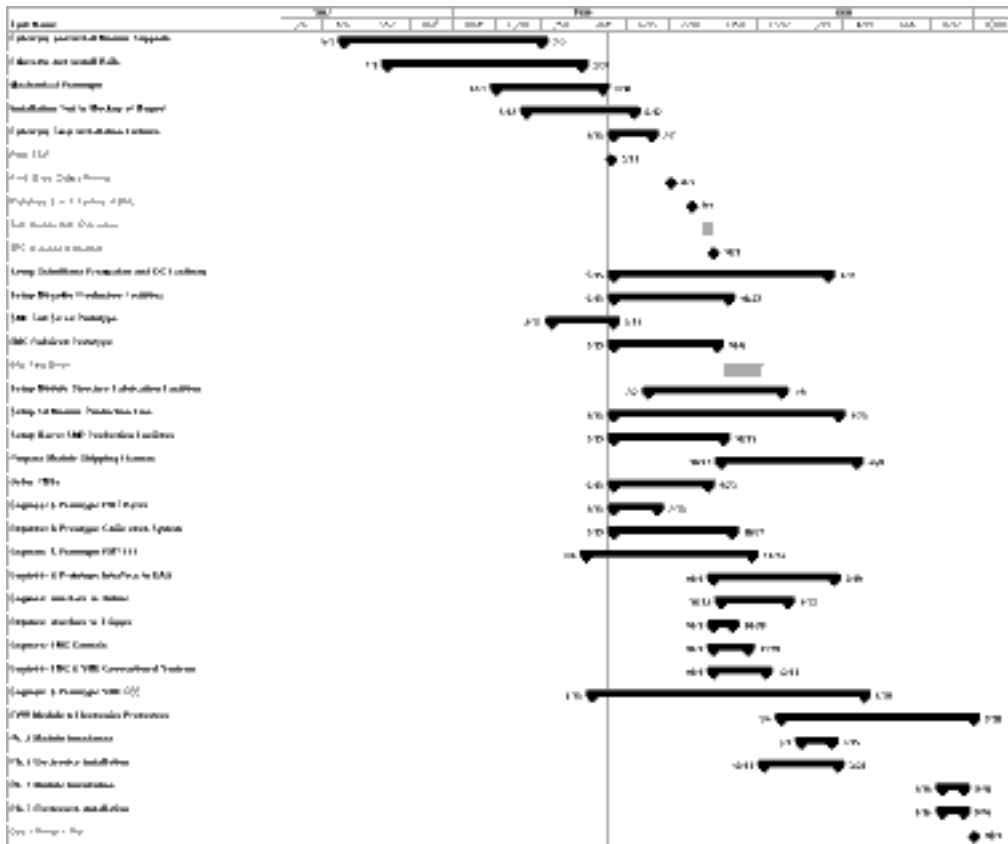


Figure X.3-1. Schedule projected for the construction of the STAR Barrel Electromagnetic calorimeter up to Day 1, given the funding profile shown in Table X.3-1 under the assumption of needing zero contingency. The time scale is given in financial years.

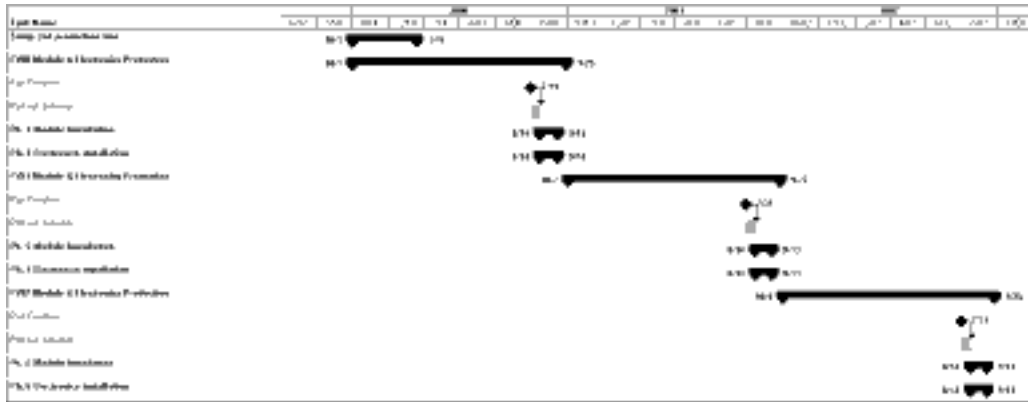


Figure X.3-2. Schedule projected for the construction of the STAR Barrel Electromagnetic calorimeter after Day 1 until completion of the calorimeter, given the funding profile shown in Table X.3-1 under the assumption of needing zero contingency. The time scale is given in financial years

X.4 Project Effort

The estimated level of effort required in order to complete the full barrel calorimeter, SMD, and optical systems for the pre-shower detector, according to the schedule presented in Figs. X.3-1 and X.3-2 is indicated by fiscal year in Figure X.4-1. The effort is shown for the following categories: Engineering (EN), Engineering Associate (EA), Drafting (DR), Administration (AD), Technician (TE), and Machinist (LA). The workload generally follows the funding profile, peaking at 28 man-years per fiscal year in FY01. The workload is higher in FY98 than FY99 primarily due to engineering associated with the setup of the module production facilities and the design of the electronics and trigger. The total effort required to complete the project is around 90 man-years. The effort level includes the sizable contributions from the collaborating institutions discussed in section X.1.

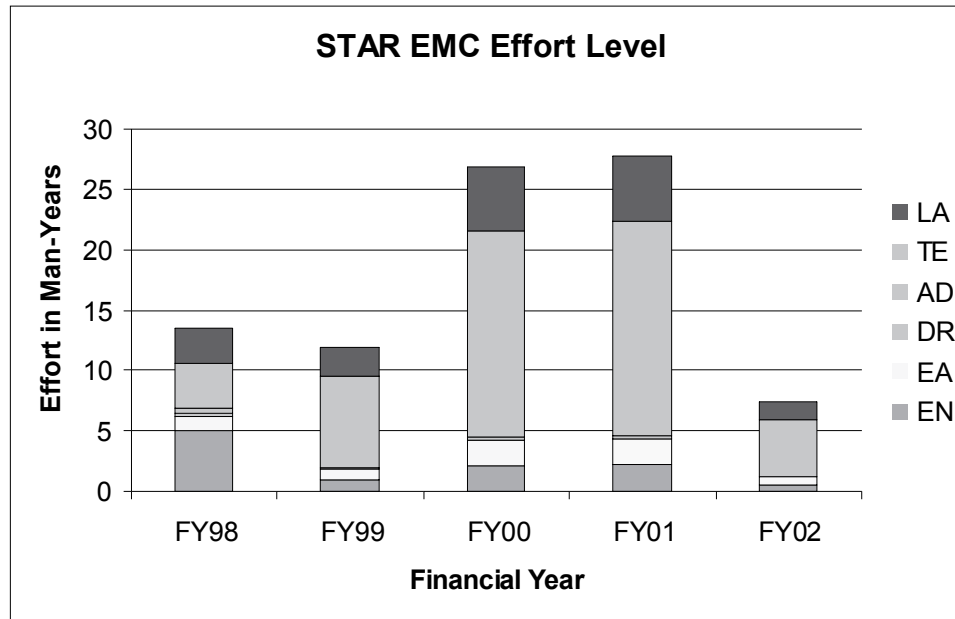


Figure X.4-1. The estimated level of effort in man years necessary for the completion of the STAR Electromagnetic Calorimeter according to the funding profile in Table X.3-1 and the schedule in Figures X.3-1 and X.3-2. The level of effort estimate assumes zero usage of contingency.